BELLCOMM, INC.

SUBJECT: Solar Wind Radiation Doses
Case 103-2

DATE: January 9, 1967

FROM: R. H. Hilberg

ABSTRACT

The sun continuously emits low energy protons which are encountered by all interplanetary and lunar missions. These protons can not penetrate spacecraft shields, but produce significant surface doses on all materials exposed to free space. Surface doses resulting from the solar wind are calculated and seem to be large, of the order of 10^9 rad per week. The proton flux varies considerably in both energy spectrum and density, so that the dose rates may vary by an order of magnitude. The dose delivered by solar wind protons depends much more on the identity of the surface material than it does for the higher energy protons present during solar flares. Additional effects from sputtering are also present, although they do not seem important for modest length missions on the basis of rather preliminary estimates.

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MEMORANDUM FOR FILE

INTRODUCTION

The sun continuously emits low energy protons which are encountered by all missions extending outside the protection of the earth's magnetosphere. These protons cannot penetrate spacecraft shields, but produce significant surface doses on all materials exposed to free space. In the case of optical materials or thermal control coatings where relatively small changes in the surfaces may be important, significant problems may arise. Some concern with this problem has arisen in regard to the Apollo optical system for navigation. As a result a model environment is being proposed for inclusion in the Natural Environment and Physical Standards document.

The average solar wind flux of $2.5 \times 10^8 \frac{\text{protons}}{\text{cm}^2\text{-sec}}$, produces a large calculated surface dose, of the order of 10^9 rad per week. However, the proton flux varies considerably in both energy spectrum, and density, so that dose rates an order of magnitude higher or lower are possible. The dose delivered by solar wind protons depends much more on the identity of the surface material than it does for the higher energy protons present during solar flares.

ENVIRONMENT

The solar wind, which is found outside the magnetosphere, is made up of low energy charged particles travelling almost radially (within 10^o) away from the sun, with velocities of the order of 500 km/sec. The particles which contribute most of the radiation dose are the protons, although a similar flux of electrons must be present to maintain net charge neutrality. Smaller fluxes of alpha particles have also been observed. The data used here are based on measurements made on IMP 1 (Ref. 1), Mariner 2 (Ref. 2), and the Vela satellites (Ref. 3).

All three sets of measurements indicate that maximum particle velocities are observed during magnetically active times, with a peak bulk velocity (averaged over several hours) of about 750 km/sec. The average bulk velocity observed on Mariner 2 (late 1962) during the declining stages of solar activity was about 500 km/sec. The Vela and IMP 1 measurements during solar minimum (late 1963 through early 1965) indicate average velocities of the order of 350 km/sec. Both the Mariner 2 and the Vela measurements indicate a density of about 5 particles/cm^3.

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The velocities above correspond to proton energies of the order of 1 Kev. The Vela data indicate that this is actually a typical mean energy. The spectrum usually seems to be about 0.5 Kev wide. At times, however, significant fluxes of protons with energies of the order of 5 Kev have been observed.

DOSE RATE CALCULATIONS

The dose in rads is defined in terms of the energy deposited per unit weight of material, with one rad representing 100 ergs absorbed per gram of absorber. Quantitatively, this dose is evaluated by the expression:

$$\text{DOSE} = 1.6 \times 10^{-8} \left(\frac{dE}{dx}\right) N(E)\, dE$$

where $\frac{dE}{dx}$ is the energy loss, in Mev/g/cm^2; N(E) is the particle flux as a function of energy, E; and the integration extends over all energies of the incident particles.

Evaluation of the energy loss term, $\frac{dE}{dx}$, is complicated by problems of both a theoretical and experimental nature. The theoretical difficulties arise from the fact that the velocity of the incident protons is comparable to the velocity of some of the orbital electrons of the target material. Under these circumstances the energy loss depends in detail on the atomic or molecular energy states of the material under consideration.* Experimental evaluation of the energy loss term is made difficult by the fact that the range of the low energy protons is so small. For example, the range of a 40 Kev proton in Argon is about 0.09 mg/cm^2. For a metallic oxide such as may be found in glass, or in optical or thermal coatings, the range of such protons is of the order of 0.1 microns (Ref. 4).

Using the experimental results for 40 Kev protons of Phillips (Ref. 5) Reynolds (Ref. 6) and Warshaw (Ref. 7), and extrapolating to 1 Kev incident proton energy using the method of Fermi and Teller (Ref. 8), an approximate value for the energy loss of $\frac{dE}{dx} \doteq 100$ Mev/g/cm^2 is found for the medium atomic number materials usually found in optical materials. The extrapolation to 1 Kev proton energy uses a linear relationship between $\frac{dE}{dx}$ and proton velocity.

*For higher energy incident protons (order of .1 Mev or higher) this is not true.

Using a particle density of 5 protons/cm^3, a bulk velocity of 500 km/sec, and an energy loss value of 100 Mev/g/cm^2, a dose rate of 400 rad/sec or 3.5×10^7 rad/day results. This dose is, however, a surface dose, extending of the order of 0.1 microns (10^{-5} cm) into the material.

EFFECTS ON MATERIALS

Some preliminary measurements have been made on both optical and thermal control coatings with ion beams in the correct range of particle energies. These measurements indicate that no serious problems exist for short duration missions outside the Earth's magnetosphere. However, preliminary results from the Research Projects Laboratory at MSFC indicate that some pigments exposed to 2×10^{16} protons/cm^2 (corresponding to about 3 years in free space) had their reflectivity reduced by about 5% in the optical region.

In addition to the ionization of the target material by solar wind bombardment there is also the effect of sputtering of surface atoms to be considered. Wehner estimates that such sputtering results in the loss of about 1 Angstrom of copper per year of exposure (Ref. 9).

CONCLUSIONS

The above considerations indicate that at least for some materials solar wind effects in the form of darkening of optical coatings and degradation of thermal control coatings may become significant for long duration lunar or planetary missions. As a result, it is recommended that environmental specifications for systems to be used on such missions include the effect of the solar wind. To implement this it is further recommended that a description of the solar wind similar to that used here be included in editions of the NEPSAP applicable to advanced missions.

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REFERENCES

1. Wolf, et. al. J.G.R. 71#5 p1319 (1966).
2. Neugebauer and Snyder, J.G.R. 71#19 p4469 (1966).
3. Coon, "Vela Satellite Measurements", Radiation Trapped in the Earth's Magnetic Field, Proceedings of the Advanced Study Institute Held at the Chr. Michelsen Institute, Bergen, Norway, August 16 - September 3, 1965. D. Reidel Publishing Co. Dordrecht-Holland
4. Whaling, Handbuch der Physik, Bd 34, Berlin. (1957).
5. Phillips, Physical Review 90 p532 (1953).
6. Reynolds, Physical Review 92 p742 (1953).
7. Warshaw, Physical Review 76#12 p1759 (1949).
8. Fermi and Teller, Physical Review 72#5 p399 (1947).
9. Wehner, "Solar Wind Bombardment of a Surface in Space" NASA-Symposium on Thermal Radiation of Solids, Session IV: Space Environmental Effects (1964). NASA TM-X-54697